AGRICULTURE

CLIMATE CHANGE, CROP PESTS AND DISEASES

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BACKGROUND

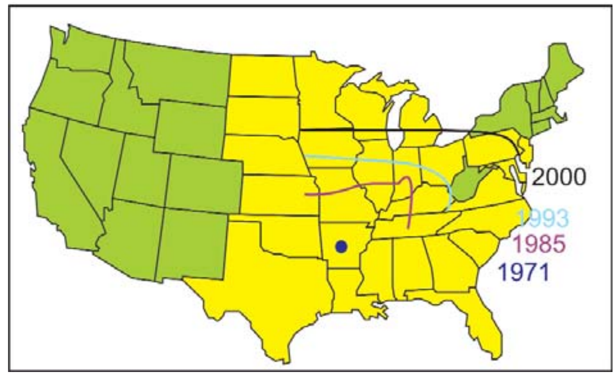
Climate change brings new stresses on the world food supply system. The United Nations' Food and Agricultural Organization (FAO) reports that for the past 20 years there has been a continual per capita decline in the production of cereal grains worldwide. As grains make up 80% of the world's food, world food supply could change dramatically with warming, altered weather patterns and changes in the abundance and distribution of pests. This case study describes the role of climate in agriculture, presents projected impacts on agriculture generated by climate change, examines the associated economic losses and addresses key issues related to risk management for agriculture.

THE ROLE OF CLIMATE: CROP GROWTH

Temperature: The metabolism, morphology, photosynthetic products, and the "root-to-shoot" ratio of crop plants (a measure of stress) are strongly affected by changes in temperatures. When the optimal range of temperatures is exceeded, crops tend to respond negatively, resulting in a drop in net growth and yield. Vulnerability of crops to damage by high temperatures varies with development stage, but most stages of vegetative and reproductive development are affected to some extent (Rosenzweig and Hillel 1998).

A warmer climate is likely to induce shifts in the optimal zonation of crops. The resulting poleward shift of crop-growing and timber-growing regions could expand the potential production areas for some countries (notably Canada and Russia), though yields might be lower where the new lands brought into production consist of poorer soils. Other constraints on shifts in crop zonation include the availability of water, technology, willingness of farmers to change crops, and sufficiency of market demand.

Figure 2.27 Soybean Sudden Death Syndrome



This map shows the northen range expansion of soybean sudden death syndrome (Fusariam solani f.sp. glycines) in North America. Source: X.B. Yang

Water: A warmer climate is projected to increase evaporation, and crop yields are most likely to suffer if dry periods occur during critical development stages, such as reproduction. Drought hastens the aging of older leaves and induces premature shedding of flowers, leaves and fruits. Moisture stress during the flowering, pollination and grain-filling stages is especially harmful to maize, soybean, wheat and sorghum. Water is the most serious limiting factor for all vegetation; it takes approximately 1,000 liters of water to produce 1 kg of biomass (Pimentel et al. 2004).

Extreme weather events: Extreme meteorological events, such as brief hot or dry spells or storms, can be very detrimental to crop yields. Excess rain can cause leaching and water logging of agricultural soils, impeded aeration, crop lodging, and increased pest infestations. Excess soil moisture in humid areas can also inhibit field operations and exacerbate soil erosion. High precipitation may prohibit the growth of certain crops, such as wheat, that are particularly prone to lodging and susceptible to insects and diseases (especially fungal diseases) under rainy conditions (Rosenzweig and Hillel 1998). Interannual variability of precipitation is already a major cause of variation in crop yields, and this is projected to increase.

THE ROLE OF CLIMATE: CROP PESTS, PATHOGENS AND WEEDS

Meteorological conditions also affect crop pests, pathogens and weeds. The range of plant pathogens and insect pests are constrained by temperature, and the frequency and severity of weather events affects the timing, intensity and nature of outbreaks of most organisms (Yang and Scherm 1997).

LOSSES ASSOCIATED WITH 1993 HEAVY PRECIPITATION AND FLOODS

Losses accounted for in Mississippi River Basin: $23 billion.
The unaccounted-for health and ecological consequences included:

- Over 400,000 cases of cryptosporidiosis in Milwaukee, with over 100 deaths in immunocompromised hosts, after flooding of sewage into Lake Michigan contaminated the city's clean water supply (Mackenzie et al. 1994).

- Doubling of the size of the Gulf of Mexico "Dead Zone" in 1993, with subsequent retraction, from increased runoff of nitrogen fertilizers after flooding.

- Emergence of hantavirus pulmonary syndrome. Six years of drought in the US Southwest reduced rodent predators, while early and heavy rains in 1993 increased their food sources, leading to 10-fold increase in rodents and the emergence of this new disease (Levins et al. 1993).

- Several cases of locally transmitted malaria in Queens, NY, associated with unusually warm and wet conditions (Zucker 1996).

Milder winters and warmer nights allow increased winter survival of many plant pests and pathogens, accelerate vector and pathogen life cycles, and increase sporulation and infectiousness of foliar fungi. Because climate change will allow survival of plants and pathogens outside their historic ranges, models consistently indicate northward (and southward in the Southern Hemisphere) range shifts in insect pests and diseases with warming (Sutherst 1990; Coakley et al. 1999). About 65% of all plant pathogens associated with US crops are introduced and are from outside their historic ranges (D. Pimentel, pers. comm. 2005), and models also project an increase in the number of invasive pathogens with warming (Harvell et al. 2002).

Sequential extremes can affect yields and pests. Droughts, followed by intense rains, for example, can reduce soil water absorption and increase the potential for flooding, thereby creating conditions favoring fungal infestations of leaf, root and tuber crops in runoff areas. Droughts, followed by heavy rains, can also reduce rodent predators and drive rodents from burrows. Prolonged anomalous periods — such as the five years and nine months of persistent El Niño conditions (1990-1995; Trenberth and Hoar 1996) — can have destabilizing effects on agriculture production, as has recurrent drought from 1998 to the present in the western US.

EXTREMES AND PESTS

- Drought encourages aphids, locust and whiteflies (and the geminiviruses they can inject into staple crops). Some fungi, such as *Aspergillus flavus* that produces aflatoxin, is stimulated during drought and it attacks drought-weakened crops (Anderson et al. 2004).

- Floods favor most fungi (mold) and nematodes (Rosenzweig et al. 2001).

Long-term field experiments discussed in the case study of aeroallergens show that weeds respond with greater reproductive capacity (pollen production) to elevated CO_2 (Wayne et al. 2002; Ziska and Caulfield 2000; Ziska et al. 2003), as do some arbuscular mycorrhizal fungi (Wolf et al 2003; Treseder et al. 2003; Klironomos et al. 1997). These changes can also influence crop growth.

TRENDS IN AGRICULTURAL PESTS

Since the 1970s, the ranges of several important crop insects, weeds, and plant diseases have expanded northward (Rosenzweig et al. 2001). In Asia, the prevalence and distribution of major diseases, such as rice blast, rice sheath blight, wheat scab, wheat downy mildew and wheat stripe rust have changed significantly. Characteristically warm-temperature diseases have increased, while cool-temperature diseases have decreased (Yang et al. 1998) For example, in China, changes in warm-temperature diseases are statistically correlated with changes in average annual temperature from 1950 to 1995 (Yang et al. 1998).

In the Western Hemisphere, plant pathologists have observed new or reemerging crop diseases during the last two decades. Significant expansion of disease ranges in major agriculture crops appears to have started in the early 1970s. Range expansion of the gray leaf blight of corn, caused by the fungus *Cercospora zeae-maydis*, first noticed in the 1970s, has now become the major cause of corn yield loss in the USA (Anderson et al. 2004). Bean pod mottle virus of soybean, vectored by bean leaf beetles, has expanded its damage range from the southern US to the northcentral region, becoming a major yield-limiting factor. The range of soybean sudden death syndrome has expanded similarly (see figure 2.27).

Many emerging diseases have become established as significant threats to major crops. According to a recent survey sponsored by the National Plant Pathology Board of the American Phytopathological Society, new diseases have emerged in almost all the major food crops in the US in the last 20 years. For several crops there are up to four reported new or emerging diseases (Rosenzweig et al. 2001).

IMPACTS ON HUMAN HEALTH AND NUTRITION

The fungus known as potato late blight was a major cause of the widespread famine that induced the great Irish migration in the 19th century. The 1943 outbreak of rice leaf blight after a flood in Bengal, India, resulted in severe crop loss followed by a famine in which two million people died of starvation.

Undernutrition is a fundamental cause of stunted physical and intellectual development in children, low productivity in adults, and susceptibility to infectious diseases. The United Nations Food and Agriculture Organization (FAO) estimates that in the late 1990s, 790 million people in developing countries did not have enough to eat (FAO 1999). The FAO figure applies to those with protein/calorie malnutrition and omits the 2 billion iron-malnourished people and others who are vitamin- and iodine-deficient (WHO 2004). By this encompassing definition, some 3.7 billion humans are currently malnourished.

Outbreaks of pests, fungi and increased growth of weeds will require the increased use of pesticides (herbicides, fungicides, insecticides). These persistent organic pollutants contaminate surface and underground water supplies and food, and threaten the health of farm workers and consumers.

ECONOMIC DIMENSIONS

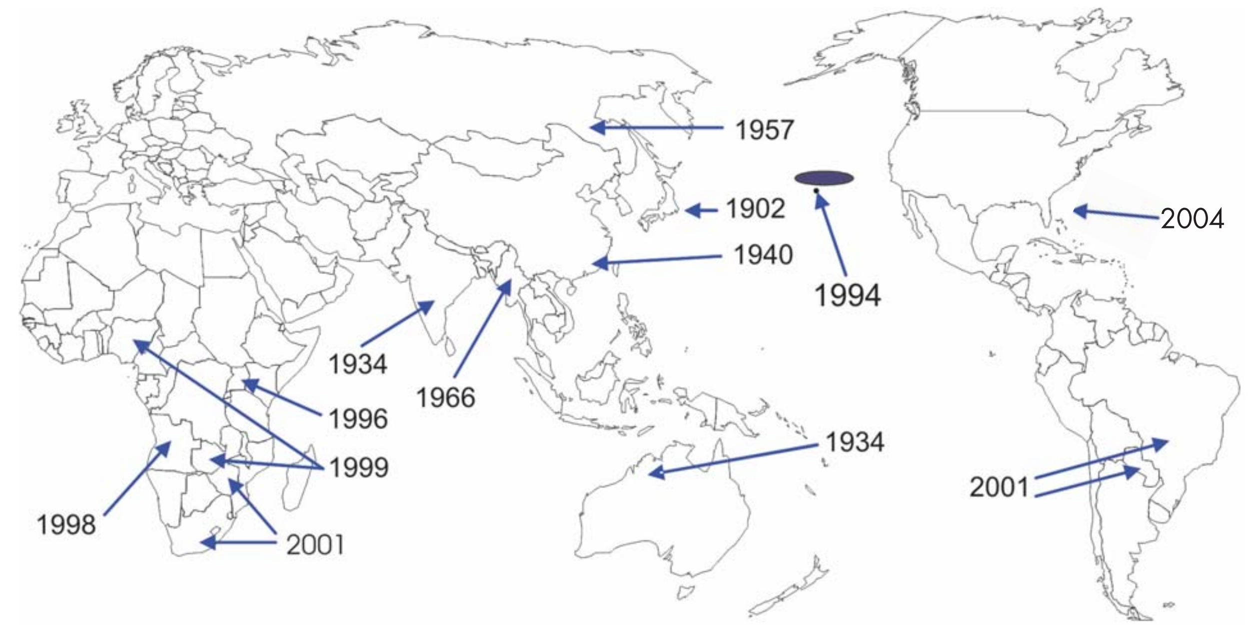
Previous economic estimates of the impacts of climate change on US agriculture are based on model projections of gradual change in temperatures (Adams et al. 1999). Mendelsohn et al. (1999) account for temperature variance in their models and find that, if interannual variation in temperature increases by 25% every month, average farm values fall by about one-third. Similar variation in precipitation decreases farm values only 6%. Notably, these models do not include changes in the timing of seasons nor the overall role of weather extremes. None take into account the impacts of pests, pathogens and weeds associated with warming and the increased variability.

Extreme weather events have caused severe damage for US farmers in the past two decades (Table 2.3 on Page 75) (Rosenzweig et al. 2001). Estimated losses from the 1988 summer drought were on the order of US $56 billion (1998 dollars) and cost the taxpayers US $3 billion in direct relief payments. The losses from the 1993 floods in the Mississippi River Valley exceeded US $23 billion, but this does not include the costs of treating and containing the associated disease outbreaks.

Worldwide, pests cause yield losses of more than 40% of potential crop value (Altaman 1993; Pimentel 1997). For tropical crops such as sugarcane, losses can be as high as 50% of potential yields. Post-harvest losses of food (primarily from rodents and mold) amount to about 20%. Taken together, pre-harvest and post-harvest losses from pests amount to about 52% of world food production.

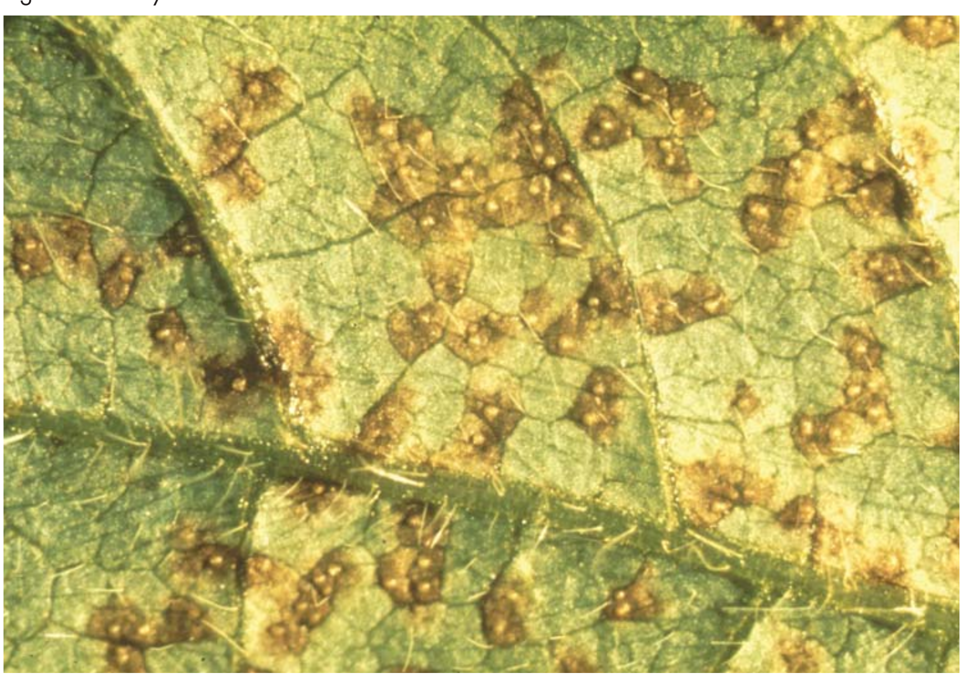
Worldwide there are about 70,000 pests (insects, plant pathogens and weeds) that damage crops. Despite 3 billion kg in pesticides applied per year, costing about US $35 billion, plus other non-chemical controls, pests destroy more than 40% of all crops with a value of about US $300 billion per year (Oerke et al. 1995). After world crops are harvested, other pests (insects, microbes, rodents and birds) destroy another 25% of world food. Thus, pests are destroying approximately 52% of all crops despite the use of pesticides and other controls (D. Pimentel, pers. comm. 2005).

Figure 2.28 Soybean Rust Introduction



World map indicating areas where soybean rust (Phakopsora pachyrizi) was first reported. Soybean rust is believed to have entered the US with dust transported by Hurricane Ivan in 2004 (Stokstad 2005).
Source: X.B. Yang

Figure 2.29 Soybean Rust



Soybean rust disrupting leaf growth.

Image: Joe Hennen. Botanical Research Institute, Fort Worth, TX.

ECONOMIC IMPACTS OF SOYBEAN DISEASES

Projected losses from introduction of soybean rust into the US were made in the early 1980s (Kuchler et al. 1984). Soybean production in the Americas accounts for over 80% of the soybean produced globally. For many years, soybean prices have been suppressed by the expansion of cropping area in South America, which now produces more soybean than is produced in North America. Expansion of global demand (mainly by Asian countries, especially China) has been offset by the expansion of areas for soybean production in South America. Consequently, soybean prices have fluctuated around US $5 to US $6/bushel with the highest being about US $8/bu and the lowest being below US $4/bu.

In 2002, US soybean farmers experienced epidemics of Soybean Sudden Death Syndrome (SDS) (see figure 2.27) and various viral diseases, causing nearly US $2 billion in losses. In the 2003 growing season, outbreaks of Asian aphids and charcoal rot — a fungal root rot disease — occurred in Iowa, Illinois and Minnesota, the three largest soybean producing states, after cool July weather suddenly turned into a record dry August. Yields in these states were 20-28% lower than those in the 2002 season and resulted in record high prices of soybean futures in the US.

The global situation was exacerbated by the introduction of soybean rust into South America, mainly in Brazil and Paraguay (see figure 2.28). Shortly after the disease was reported in 2001 in South America, severe epidemics occurred in the 2003 growing season, resulting in losses of US $1.3 billion in Brazil alone, despite mass application of fungicides.

In 2004, soybean rust was worse than in 2003. The disease occurred early and, in central and northern Brazil, excessive rains favored its development. Losses in 2004 were over US $2.3 billion. According to a report presented by Brazilian plant pathologists at World Soybean Research Conference (March 2004), US $ 750 million worth of fungicides were used to control soybean rust in 2003 and fungicide use has surpassed herbicide use in Brazil.

The year 2004 also brought drought to soybean producing regions in southern Brazil and Argentina, inducing widespread "charcoal rot," another fungal disease. The estimated yield reduction due to drought and charcoal rot was 30% in southern Brazil (USDA 16 Aug 2004). Such yield reductions in both North and South America have raised the price of soybean from around US $5/bu in 2003 August to near US $11/bu for soybean delivered in May 2004. It reached US $14/bu for a short period in 2004. It is predicted that 30% of soybean producers in Mato Grosso, Brazil, the largest soybean production region in the world, will be out of business in the next several years due to soybean rust (Hiromoto 2004).

Most recently, soybean rust is thought to have been introduced into the US by Hurricane Ivan, one of the four to hit Florida in fall 2004 (Stokstad 2004). The fungal disease rapidly spread to 11 states and it is estimated by the USDA that soybean rust will cost American farmers US $240 million to US $2 billion/year within three to five years (Livingston et al. 2004).

Soybean Field

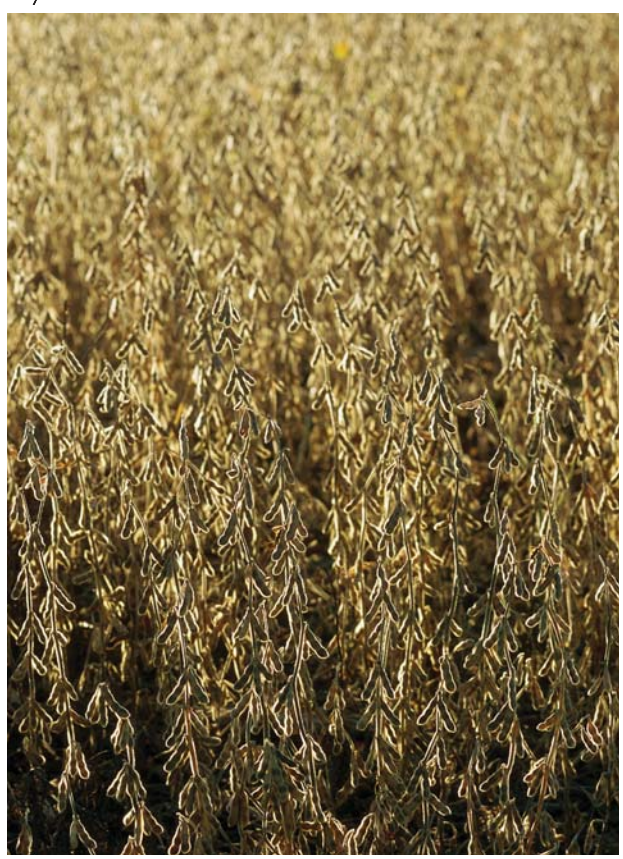


Image: Corbis

Table 2.3 Extreme Weather Events Causing Severe Crop Damage in the US: 1977-2003

Year	Geographical area	Extreme weather event and US losses
1970	U.S.A. Southern States	Southern corn blight (pest). Total losses: $56 billion
1977	U.S.A. Southern States	Drought induced high aflatoxin concentration in corn, costing producers more than $80 million.
1977	U.S.A. Corn Belt	Drought disrupted domestic and export corn marketing.
1980	U.S.A. Central and Eastern regions	Summer drought and heat wave.
1983	U.S.A. Southern States	Drought induced high aflatoxin concentration in corn costing producers more than $97 million.
1983	U.S.A. Corn Belt	Drought disrupted domestic and export corn marketing.
1986	U.S.A. Southeast	Summer drought and heat wave.
1988	U.S.A. Central and Eastern regions	Summer drought and heat wave. Congress paid farmers over $3 billion for crop losses. Total losses: $56 billion.
1990	U.S.A. Texas, Oklahoma, Louisiana, Arkansas	Flooding in spring.
1993	U.S.A. Midwest	Flooding in summer affecting 16,000 square miles of farmland, and damaging crops in over 11 million acres. Crop losses over $3 billion. Total losses exceeded $20 billion.
1993	U.S.A. Southeast	Drought and heat wave in the summer, causing the loss of 90% of corn, 50% of soybean, and 50% of wheat crops. Crop losses over $1 billion.
1994	U.S.A. Texas	Severe flooding.
1995	U.S.A. Southern Plains	Severe flooding.
1995	U.S.A. Texas, Oklahoma, Louisiana, Mississippi, California.	Severe flooding.
1996	U.S.A. Pacific Northwest, Appalachian, Mid-Atlantic and Northeast	Severe flooding.
1997	U.S.A. Northern Plains, Arkansas, Missouri, Mississippi, Tennessee, Illinois, Indiana, Kentucky, Ohio, West Virginia	Severe flooding.
1997	U.S. West Coast	Severe flooding from December 1996 to January

Sources: National Climatic Data Center, NOAA; X.B. Yang, personal communication

THE FUTURE

CCF-I: ESCALATING IMPACTS

Climate change will affect agriculture around the globe. A changing climate will alter the hydrological regime, the timing of seasons, the arrival of pollinators and the prevalence, extent, and type of crop diseases and pests. Globalization and intensification techniques may also contribute to new configurations of plant-pest relationships that affect cultivated and wild plants.

A warming of 1°C is estimated to decrease wheat, rice and corn yields by 10% (Brown 2002). Warming of several °C or more is projected to alter production significantly and increase food prices globally, increasing the risk of hunger in vulnerable populations (Houghton et al. 2001). Particularly large crop losses become more likely when extreme weather events produce favorable conditions for pest outbreaks.

Climate change can lead to the resurgence of pre-existing pathogens or can provide the conditions for introduced pathogens to thrive. Milder winters and higher overall temperatures will facilitate winter survival of plant pathogens and invasive species, and accelerate vector and pathogen life cycles (foliar fungi, bacteria, viruses) (Anderson et al. 2004).

While global average water vapor concentration and precipitation are increasing, irrigation requirements are projected to increase in some agricultural regions and larger year-to-year variations in precipitation are very likely over most areas (Houghton et al. 2001). These changes will likely lead to increased outbreaks of foliar fungal diseases, such as soybean rust. Warming and increased precipitation and accompanying diseases would increase the use (and costs) of pesticides for certain crops, such as corn, cotton, potatoes, soybeans and wheat (Chen and McCarl 2001).

Models for cereal crops indicate that, in some temperate areas, potential yields increase with small temperature increases, but decrease with large temperature rises. In most tropical and subtropical regions, however, potential yields are projected to decrease under all projected temperature changes, especially for dryland/rainfed regions where rainfall decreases substantially.

The impacts of climate change, therefore, will fall disproportionately upon developing countries and on the poor within all countries, exacerbating inequities in health status and access to food, clean water and other basic resources. Shortages in food supply could generate distortions in international trade at regional and global levels, and disparities and disputes could become more pronounced over time (Houghton et al. 2001).

CCF-II: SURPRISE IMPACTS

The current trajectory for warming and more violent and unpredictable weather could have catastrophic effects on agricultural yields in the tropics, subtropics and temperate zones. Disease outbreaks could take an enormous toll in developing nations, and overuse of pesticides could breed widespread resistance among pests and the virtual elimination of protective predators.

With pests currently causing yield losses over 40% worldwide (Altaman 1993), losses could climb steeply to include the majority of food crops, especially for tropical crops such as sugarcane, for which current annual losses often exceed 50% under today's conditions. With production of the eight most vital foods on the order of US $300 billion annually, and over 50% growing and stored grains now lost to pests, pathogens and weeds, more warming, weather extremes and pests could drive losses in particularly devastating years well over US $150 billion per annum. Multi-regional food shortages could lead to political instability.

SPECIFIC RECOMMENDATIONS

Early warning systems of extreme events can aid in the a) selection of seeds, b) timing of planting, and c) planning for petrol, petrochemical and fertilizer requirements.

Figure 2.30 Healthy Corn Fields

Image: Shaefer Elvira/Dreamstime

General measures to reduce the impacts of weather extremes and infestations include:

- No tillage agriculture.
- Maintaining crop diversity that helps limit disease spread.
- Maintaining flowering plants that support pollinating insects and birds.
- Maintaining trees around plots that serve as windbreakers and provide homes for worm- and insect-eating birds.
- Integrated pest management and organic farming, as toxic chemicals can kill pollinators (birds, bees and butterflies), predators of herbivorous insects (ladybugs and parasitic wasps), and predators of rodents (owls, hawks and eagles).
- Appropriate national and international food policies (subsidies, tariffs, prices) are needed to provide the proper incentives for sustainable agriculture.

The farming sector can also profitably contribute to climate solutions. Such measures include:

- Soil and plant biomass carbon sequestration.
- Methane capture for energy generation.
- Plants and animals used to produce biofuels.
- Plants for biodiesel.
- Solar panel arrays.
- Wind farms.

Integrated systems, with a diversity of crops and of surrounding ecological zones, can provide strong generalized defenses in the face of weather extremes, pest infestations and invasive species. The mitigation options to absorb carbon and generate energy cleanly can become a significant part of farming activities and contribute significantly to stabilizing the climate.

MARINE ECOSYSTEMS

CASE 1. THE TROPICAL CORAL REEF

Raymond L. Hayes

BACKGROUND

Threats to coral reefs constitute one of the earliest and clearest marine ecosystem impacts of global climate change. Coral reefs are in danger worldwide from warming-induced bleaching and multiple emerging diseases. Their decline was first apparent in the early 1980s and reef death has progressed steadily since (Williams and Bunkley-Williams 1990). Approximately 27% of reefs worldwide have been degraded by bleaching, while another 60% are deemed highly vulnerable to bleaching, disease and subsequent overgrowth by macro-algae (Bryant et al. 1998). Mortality of reefs in the Caribbean islands of Jamaica, Haiti and the Dominican Republic is now over 80% (Burke 2004).

This level of impact — with continued ocean warming and pollution — could lead to collapse of the reefs entirely within several decades. While ecological systems can reach thresholds and collapse suddenly, their recovery and reorganization into a new equilibrium could be very slow (Maslin 2000).

Coral reefs provide numerous ecological functions for marine life and serve as physical buffers that protect low-lying tropical islands and coastal zones against storms. The total value of reef-related shoreline protective services in the Caribbean region has been estimated to be between US $740 million and US $2.2 billion per year. Depending upon the degree of development, this coastal-protection benefit ranges from US $2,000 to US $1,000,000 per kilometer of coastline (Burke and Maidens 2004).